Physical and cognitive functioning of people older than 90 years: a comparison of two Danish cohorts born 10 years apart

Kaare Christensen, Mikael Thinggaard, Anna Oksuzyan, Troels Steenstrup, Karen Andersen-Ranberg, Bernard Jeune, Matt McGue, James W Vaupel

Summary

Background A rapidly increasing proportion of people in high-income countries are surviving into their tenth decade. Concern is widespread that the basis for this development is the survival of frail and disabled elderly people into very old age. To investigate this issue, we compared the cognitive and physical functioning of two cohorts of Danish nonagenarians, born 10 years apart.

Methods People in the first cohort were born in 1905 and assessed at age 93 years (n=2262); those in the second cohort were born in 1915 and assessed at age 95 years (n=1584). All cohort members were eligible irrespective of type of residence. Both cohorts were assessed by surveys that used the same design and assessment instrument, and had almost identical response rates (63%). Cognitive functioning was assessed by mini-mental state examination and a composite of five cognitive tests that are sensitive to age-related changes. Physical functioning was assessed by an activities of daily living score and by physical performance tests (grip strength, chair stand, and gait speed).

Findings The chance of surviving from birth to age 93 years was 28% higher in the 1915 cohort than in the 1905 cohort (6·50% *vs* 5·06%), and the chance of reaching 95 years was 32% higher in 1915 cohort (3·93% *vs* 2·98%). The 1915 cohort scored significantly better on the mini-mental state examination than did the 1905 cohort (22·8 [SD 5·6] *vs* 21·4 [6·0]; p<0·0001), with a substantially higher proportion of participants obtaining maximum scores (28–30 points; 277 [23%] *vs* 235 [13%]; p<0·0001). Similarly, the cognitive composite score was significantly better in the 1915 than in the 1905 cohort (0·49 [SD 3·6] *vs* 0·01 [SD 3·6]; p=0·0003). The cohorts did not differ consistently in the physical performance tests, but the 1915 cohort had significantly better activities of daily living scores than did the 1905 cohort (2·0 [SD 0·8] *vs* 1·8 [0·7]; p<0·0001).

Interpretation Despite being 2 years older at assessment, the 1915 cohort scored significantly better than the 1905 cohort on both the cognitive tests and the activities of daily living score, which suggests that more people are living to older ages with better overall functioning.

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Danish Aging Research Center, Institute of Public Health (Prof K Christensen MD, M Thinggaard MSc, A Oksuzyan MD, K Andersen-Ranberg MD, B Jeune MD, Prof J W Vaupel PhD), **Department of Biostatistics** (T Steenstrup PhD), **and Max Planck Odense Center** (K Christensen, J W Vaupel), **University of Southern Denmark, Odense, Denmark; Department of Clinical Genetics** (K Christensen), **Department of Clinical Biochemistry and Pharmacology** (K Christensen), **and Department of Geriatrics** (K Andersen-Ranberg), **Odense University Hospital, Odense, Denmark; Department of Psychology, University of Minnesota, Minneapolis, MN, USA** (Prof M McGue PhD)**; and Max Planck Institute for Demographic Research, Rostock, Germany** (J W Vaupel)

Correspondence to: Prof Kaare Christensen, Danish Aging Research Center, University of Southern Denmark, Institute of Public Health, Epidemiology, JB Winsløws Vej 9B, DK-5000 Odense C, Denmark
kchristensen@health.sdu.dk

Introduction

A 2011 report[1] from the US Census Bureau, commissioned by the US National Institute on Aging, concluded that the population of people aged 90 years and older will continue to grow in the USA, both in absolute terms and as a proportion of elderly people. The 720 000 people aged 90 years and older in 1980 in the USA had more than doubled to 1·5 million by 2010. A similar development has been seen in other high-income countries. Even in Denmark, which has one of the lowest life expectancies in western Europe,[2] the chance of surviving into the tenth decade of life has gone up by roughly 30% per decade for people born in 1895, 1905, and 1915.[3] This increase is based both on a decrease in early-life mortality at the beginning of the 20th century and a reduction in mortality for elderly people in the second half of the century.[4]

Serious concern has emerged about the substantial and increasing number of individuals in each birth cohort who can be expected to survive into their 90s.[5] Life extension might provide only increased chances of being frail or existing in a vegetative state, with huge personal and societal costs. Research in the mid-1990s looked into this so-called failure-of-success hypothesis, that increased longevity (due to falling mortality from chronic diseases) meant that the health of elderly people was declining.[6] However, as can be noted from a 2011 review by Crimmins and Beltrán-Sánchez,[7] very few data exist on this topic for very elderly people or for people living in residential care, for whom the issue is most relevant.

In younger elderly people (ages 65–85 years) mixed results have been reported, but generally more recent birth cohorts have more diseases (partly because of improved diagnostics), possibly better physical functioning, and consistently better cognitive functioning than do earlier birth cohorts—designated as the Flynn effect.[4,7–9] As such, more recent cohorts of younger elderly people could be expected to reach their tenth decade in better health than earlier cohorts. However, some researchers have suggested that cohort differences that exist in younger elderly people could be eliminated at older ages by mortality-related processes.[10] In this study, we investigate two complete Danish birth cohorts of nonagenarians born 10 years apart, in 1905 and 1915.

Methods

Study population

The 1905 cohort study took place from August to October, 1998, and included all Danes born in 1905 who lived in Denmark at the time of the survey, a total of 3600 people aged 92–93 years. The 1915 cohort study took place 12 years later, from September to November, 2010, and included all Danes born in 1915 who lived in Denmark at the time of the survey, a total of 2509 people aged 94–95 years.

See Online for appendix

The two surveys used the same design and survey instrument. No exclusion criteria were applied: all individuals born in Denmark and living in Denmark during the relevant study periods were approached, irrespective of type of residence, health, or cognitive status.[11–13] The cohorts were identified through the Danish Civil Register System, which since 1968 has kept a record of all people living in Denmark. This system ensures identification and follow-up of all participants, provided that they have not emigrated.

Assessment procedure

Both studies used similar ascertainment and assessment protocols. A proxy responder was encouraged to participate in the interview if the cohort member was unable to participate because of mental or physical handicap. In most cases, the survey took place in the participants' homes and was done by one of roughly 100 interviewers from the Danish National Institute of Social Research. The assessment consisted of an interview, physical and cognitive tests, and the collection of biological material (eg, blood spot or cheek swab). The assessment procedure has been described in detail elsewhere.[11–13] We focused on basic activities of daily living, physical performance tests (grip strength, chair stand, and gait speed), cognitive functioning (mini-mental state examination and a composite of five cognitive tests sensitive to age-related changes), and depression symptomatology—all outcomes that we have studied extensively with the same reliable and validated instrument in these and other cohorts of elderly people.[14–17] The appendix describes the survey instrument in detail.

Statistical analyses

Comparison of the cohorts' physical and cognitive functioning and other characteristics was done separately for men and women and for both sexes combined by use of standard statistical methods: χ^2 tests or t tests, with the assumption of either equal or unequal variance. Sex-by-cohort interaction analyses and adjustment for auxiliary variables were done with regression models.

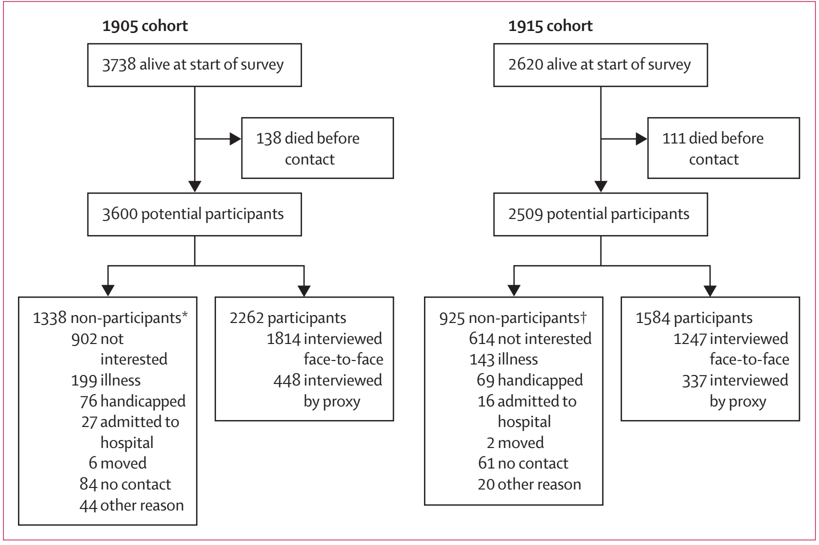

Figure: **Study profile for 1905 and 1915 cohorts**

*For the non-participants from the 1905 cohort, mean age was 93·2 years and 265 (20%) were men. †For the non-participants from the 1915 cohort, mean age was 95·3 years and 172 (19%) were men.

	1905 cohort (n=2262)	1915 cohort (n=1584)	p value
Age in years	93·1 (0·3)	95·3 (0·3)	<0·0001*
Men	584 (26%)	394 (25%)	0·508†
Participation by proxy			
Both sexes	448 (20%)	337 (21%)	0·266†
Men	90 (15%)	58 (15%)	0·768†
Women	358 (21%)	279 (23%)	0·180†
In residential care‡			
Both sexes	1067 (47%)	765 (48%)	0·527†
Men	243 (42%)	169 (43%)	0·723†
Women	824 (49%)	596 (50%)	0·631†
Education			
Both sexes§			0·006†
No vocational education	1475 (68%)	962 (63%)	
Vocational education	428 (20%)	347 (23%)	
Higher education	280 (13%)	229 (15%)	
Missing data	79 (3%)	46 (3%)	0·356†
Men§			0·087†
No vocational education	271 (49%)	162 (43%)	
Vocational education	190 (34%)	127 (34%)	
Higher education	97 (17%)	86 (23%)	
Missing data	26 (4%)	19 (5%)	0·877†
Women§			0·005†
No vocational education	1204 (74%)	800 (69%)	
Vocational education	238 (15%)	220 (19%)	
Higher education	183 (11%)	143 (12%)	
Missing data	53 (3%)	27 (2%)	0·168†

Data are n (%) or mean (SD), unless otherwise indicated. *Test of equal mean with an assumption of equal variance. †Test of equal proportions (χ^2 test or Fisher's exact test). ‡Nursing home or sheltered housing facility. §Missing data are excluded from other percentage calculations.

Table 1: **Demographic characteristics of the 1905 and 1915 cohorts**

Role of funding the source

The sponsors of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report. KC and JWV had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Results

2262 (63%) people participated in the 1905 cohort study, 1814 (80%) of whom were interviewed in person and 448 (20%) via a proxy participant. 1584 (63%) people participated in the 1915 cohort study, 1247 (79%) of whom were interviewed in person and 337 (21%) by proxy (figure, table 1).

On the basis of the Danish cohort life tables,[3] the chance of surviving from birth to age 93 years was 28% higher in the 1915 cohort than in the 1905 cohort (6·50% *vs* 5·06%), and the chance of reaching 95 years was 32% higher in 1915 cohort (3·93% *vs* 2·98%). Despite being on average 2·2 years older than the 1905 cohort, members of the 1915 cohort performed better than did members of the 1905 cohort in both cognitive functioning and activities of daily living (tables 2, 3). The average score for the mini-mental state examination was significantly higher in the 1915 cohort than in the 1905 cohort, and the 1915 cohort had a substantially higher proportion of participants with maximum scores (28–30 points; table 2). Similarly, the cognitive composite score was significantly better in the 1915 cohort than in the 1905 cohort (p=0·0003; table 2). The improved cognitive functioning in the later cohort was noted in both men and women (table 2) and in all but one of the subcomponents of the cognitive composite test (data not shown). Within both cohorts, men had better scores than did women for both the mini-mental state examination and the cognitive composite tests (table 2).

Educational attainment, which was assessed as self-reported highest educational achievement, was slightly higher in the 1915 cohort than in the 1905 cohort (table 1). The difference was significant only in women, who had very low educational attainment in both cohorts (74% and 69% had no vocational education in the 1905 and the 1915 cohorts, respectively; table 1). The 1915 cohort still had higher mini-mental state examination (linear regression coefficient 1·13, 95% CI 0·71–1·56) and cognitive composite scores (linear regression coefficient 0·36, 95% CI 0·09–0·62) after adjustment for this improvement in education. Depression symptomatology scores did not differ between the cohorts for either sex (table 2).

The 1915 cohort scored significantly better than did the 1905 cohort on the activities of daily living scale for both

	Both sexes			Men			Women		
	1905 cohort (n=1814)	1915 cohort (n=1247)	p value	1905 cohort (n=494)	1915 cohort (n=336)	p value	1905 cohort (n=1320)	1915 cohort (n=911)	p value
Cognitive composite score									
Mean (SD)	0·01 (3·6)	0·49 (3·6)	0·0003*	0·12 (3·6)	0·76 (3·6)	0·012*	–0·03 (3·6)	0·38 (3·6)	0·008*
Median (IQR)	0·05 (–2·25 to 2·26)	0·30 (–1·93 to 2·69)		0·09 (–2·23 to 2·30)	0·55 (–1·69 to 3·06)		0·05 (–2·25 to 2·24)	0·15 (–1·98 to 2·62)	..
Missing data, n (%)	30 (2%)	30 (2%)	0·146†	8 (2%)	6 (2%)	1·000†	22 (2%)	24 (3%)	0·130†
Mini-mental state examination results									
Mean (SD)	21·4 (6·0)	22·8 (5·6)	<0·0001‡	22·1 (6·0)	23·6 (5·8)	0·0003‡	21·2 (6·0)	22·5 (5·5)	<0·0001‡
Median (IQR)	23·0 (18·0–26·0)	24·0 (19·0–27·0)		24·0 (19·0–26·0)	25·0 (20·5–28·0)		23·0 (18·0–26·0)	24·0 (19·0–27·0)	
Missing data, n (%)	16 (1%)	24 (2%)	0·015†	2 (<1%)	4 (1%)	0·229†	14 (1%)	20 (2%)	0·035†
Grouped results, n (%)§			<0·0001†			<0·0001†			<0·0001†
0–17 (severe impairment)	400 (22%)	209 (17%)		86 (17%)	53 (16%)		314 (24%)	156 (18%)	
18–22 (mild impairment)	458 (25%)	281 (23%)		121 (25%)	60 (18%)		337 (26%)	221 (25%)	
23–27 (normal)	705 (39%)	456 (37%)		206 (42%)	112 (34%)		499 (38%)	344 (39%)	
28–30 (maximum)	235 (13%)	277 (23%)		79 (16%)	107 (32%)		156 (12%)	170 (19%)	
Depression symptomatology scores									
Mean (SD)	25·4 (6·3)	25·6 (6·3)	0·453*	24·8 (6·1)	24·9 (6·3)	0·928*	25·6 (6·3)	25·8 (6·4)	0·414*
Median (IQR)	24·0 (20·0–29·0)	24·0 (20·0–30·0)		24·0 (20·0–29·0)	24·0 (20·0–29·0)		24·0 (21·0–29·0)	25·0 (21·0–30·0)	
Missing data, n (%)	75 (4%)	22 (2%)	<0·0002†	23 (5%)	5 (1%)	0·017†	52 (4%)	17 (2%)	0·006†
Grouped results, n (%)§¶			0·173†			0·633†			0·281†
Score 17–20	438 (25%)	310 (25%)		135 (29%)	102 (31%)		303 (24%)	208 (23%)	
Score 21–24	504 (29%)	312 (25%)		133 (28%)	80 (24%)		371 (29%)	232 (26%)	
Score 25–29	389 (22%)	293 (24%)		103 (22%)	74 (22%)		286 (23%)	219 (24%)	
Score 30–50	408 (23%)	310 (25%)		100 (21%)	75 (23%)		308 (24%)	235 (26%)	

*Test of equal mean, with an assumption of equal variance (test of equal variance is not rejected). †Test of equal proportions (χ^2 test or Fisher's exact test). ‡Test of equal mean, without an assumption of equal variance (test of equal variance is rejected). §Missing data are excluded from the totals for percentage calculations. ¶Grouped by dividing the total distribution into quartiles.

Table 2: **Cognitive measures and depression symptomatology for the 1905 and 1915 cohorts (in-person participants only)**

	Both sexes			Men			Women		
	1905 cohort	1915 cohort	p value	1905 cohort	1915 cohort	p value	1905 cohort	1915 cohort	p value
All participants (in person and proxy), n	2262	1584	..	584	394	..	1678	1190	..
Activities of daily living score									
Mean (SD)	1·8 (0·7)	2·0 (0·8)	<0·0001*	2·1 (0·8)	2·3 (0·9)	0·0001*	1·7 (0·7)	1·9 (0·8)	<0·0001*
Median (IQR)	1·6 (1·2–2·4)	1·8 (1·3–2·6)	..	2·0 (1·3–2·7)	2·3 (1·5–3·1)	..	1·5 (1·2–2·2)	1·7 (1·2–2·5)	..
Missing data, n (%)	34 (2%)	37 (2%)	0·068†	6 (1%)	12 (3%)	0·028†	28 (2%)	25 (2%)	0·402†
Grouped results, n (%)‡			<0·0001†			<0·0001†			<0·0001†
<2	1381 (62%)	835 (54%)		281 (49%)	153 (40%)		1100 (67%)	682 (59%)	..
2–<3	705 (32%)	447 (29%)		229 (40%)	121 (32%)		476 (29%)	326 (28%)	
≥3	142 (6%)	265 (17%)		68 (12%)	108 (28%)		74 (4%)	157 (13%)	
In-person participants only, n	1814	1247		494	336		1320	911	
Grip strength									
Mean (SD)	16·1 (6·6)	16·2 (6·6)	0·699§	22·8 (6·5)	23·0 (6·6)	0·608§	13·5 (4·4)	13·5 (4·3)	0·819§
Median (IQR)	15·0 (12·0–20·0)	15·0 (12·0–20·0)	..	22·0 (18·0–27·0)	23·0 (18·0–28·0)	..	14·0 (10·0–17·0)	14·0 (11·0–16·0)	..
Missing data, n (%)	189 (10%)	189 (15%)	0·0001†	35 (7%)	30 (9%)	0·358†	154 (12%)	159 (17%)	0·0001†
Chair stand results, n (%)‡			0·002†			0·077†			0·015†
Cannot	132 (8%)	127 (10%)		33 (7%)	30 (9%)		99 (8%)	97 (11%)	..
Can, with use of arms	683 (40%)	524 (43%)		154 (32%)	127 (38%)		529 (42%)	397 (45%)	
Can, without use of arms	910 (53%)	573 (47%)		288 (61%)	175 (53%)		622 (50%)	398 (45%)	
Missing data	89 (5%)	23 (2%)	<0·0001†	19 (4%)	4 (1%)	0·029†	70 (5%)	19 (2%)	0·0001†
Gait speed (time to walk 3 m in s)									
Mean (SD)	6·5 (3·1)	6·1 (2·7)	0·004*	5·7 (3·1)	5·6 (2·6)	0·749*	6·8 (3·1)	6·3 (2·8)	0·002*
Median (IQR)	5·8 (4·1–8·0)	5·3 (4·2–7·3)	..	4·7 (3·7–6·8)	5·0 (3·9–6·5)	..	6·0 (4·5–8·4)	5·5 (4·3–7·6)	..
Not able to walk, n (%)¶	199 (12%)	181 (15%)	0·026†	55 (12%)	37 (11%)	0·822†	144 (12%)	144 (16%)	0·006†
Missing data, n (%)	323 (18%)	239 (19%)	0·342†	73 (15%)	58 (17%)	0·334†	250 (19%)	181 (20%)	0·586†
Grouped results, n (%)||			0·011†			1·000†			0·003†
<8 s	957 (74%)	653 (79%)		301 (82%)	198 (82%)		656 (71%)	455 (78%)	..
≥8 s	335 (26%)	174 (21%)		65 (18%)	43 (18%)		270 (29%)	131 (22%)	

Results for the activities of daily living (ADL) scores are reported for all participants (in person and proxy); physical performance results are reported only for participants who were interviewed in person. *Test of equal mean, without an assumption of equal variance (test of equal variance is rejected). †Test of equal proportions (χ^2 test or Fisher's exact test). ‡Missing data are excluded from the totals for percentage calculations. §Test of equal mean, with an assumption of equal variance (test of equal variance is not rejected). ¶Percentage calculations for numbers not able to walk are based on total numbers for whom this information was available (numbers not shown). ||Missing data and data for participants unable to walk are excluded from the totals for percentage calculations.

Table 3: **Activities of daily living and physical performance scores for the 1905 and 1915 cohorts**

sexes, with men scoring significantly better than women within both cohorts (table 3). However, the physical performance tests showed mixed results between cohorts. We noted no difference between the 1905 cohort and the 1915 cohort with respect to grip strength for either men or women, whereas members of the 1905 cohort did slightly better in the chair stand test than did members of the 1915 cohort (table 3). Gait speed, which was measured as the time taken to walk 3 m, was marginally better in the 1915 cohort than in the 1905 cohort, but more members of the 1915 cohort were unable to walk (table 3). We recorded no sex-by-cohort interaction for any of the outcomes—ie, the change between the cohorts was the same for men and women.

The two cohort studies did not differ in response rate, proportion of proxy respondents, or reasons for non-participation (figure). The reasons for use of a proxy respondent were the same in both cohorts, with dementia of the cohort members the most common reason in both (58% [259/445; data for 3 missing] in the 1905 cohort and 54% [168/310; data for 27 missing] in the 1915 cohort). The average percentages of missing data were similar in both studies, and varied from item to item dependent on whether the 1905 or the 1915 cohort had the highest percentage of missing data (tables 2, 3). We did a sensitivity analysis for cognitive functioning by classification of all proxy participants and all participants with missing data as having scored less than the maximum score category (28–30 points) on the mini-mental state examination. The proportion with maximum scores in the 1915 cohort versus the 1905 cohort changed from 23% versus 13% ($p<0·0001$) to 17% versus 10% ($p<0·0001$)—ie, still a significant cohort difference. We also did a sensitivity analysis for grip strength, for which more data were missing in the 1915 cohort than in the 1905 cohort. When all individuals with missing data for grip strength were assigned to the worst category (<20 kg) the results for the two cohorts still did not differ significantly (data not shown).

Discussion

Despite being on average 2·2 years older and coming from a cohort in which about 30% more people survived to age 93–95 years, the 1915 cohort performed significantly better than did the 1905 cohort both in cognitive functioning and activities of daily living (panel). We noted no consistent differences between cohorts in the physical performance tests (grip strength, chair stand, and gait speed). This finding suggests that the basis for the improved activities of daily living score in the later cohort is improved cognitive functioning and living conditions in elderly people, as well as better aids to support mobility and independence (eg, walking aids, sophisticated grab bars, threshold ramps, swivel seats). Together these factors enable improved functioning with the same physical resources. This interpretation is supported by the results of a cross-sectional study in Sweden of more than 2000 people aged 60–93 years, which showed an association between cognitive functioning and postural control.[21]

Two opposing processes affect the health of successive cohorts. On the one hand, a later cohort might benefit from health progress resulting from more effective disease prevention (eg, influenza vaccination and drugs to control high blood pressure and cholesterol), improved treatment (eg, of heart disease and cancer), and the health benefits of improved standards of living, increased educational achievement, and healthier lifestyles (eg, improved diet and exercise). Such progress helps the members of the later cohort to reach older ages in better health. This process is known as the success-of-success effect: improvements in health at earlier ages result in a healthy cohort at older ages. On the other hand, the later cohort is larger than the earlier one because of the lives that have been saved: the additional survivors might be in relatively poor health and might have died if they had lived in earlier cohorts with less favourable living conditions and poorer medical treatments. This process is known as the failure-of-success effect: saving lives might reduce average health by enabling very frail individuals to reach older ages than they would otherwise have done. For the 1915 cohort compared with the 1905 cohort, the success-of-success effect outweighed the failure-of-success effect with respect to cognitive functioning and activities of daily living, whereas the two effects apparently counterbalanced each other with respect to physical functioning.

Cognitive functioning showed the clearest improvement between the two cohorts. At younger ages (ie, <85 years) very solid evidence exists for the Flynn effect—ie, that cohorts born later typically have better cognitive function than do those born earlier.[8,22] According to the results of a US study,[10] decrease in cognitive function from age 50 years to 80 years is significantly lower in later-born cohorts than in those born earlier. More recent cohorts of elderly people could therefore be expected to reach their ninth and tenth decades in better cognitive health than earlier cohorts. Our finding of a clear improvement in cognitive functioning between cohorts of nonagenarians can be interpreted as evidence that a Flynn effect is maintained in very elderly people, rather than erased by mortality-related processes.[10] Improvements in education are likely to be a major underlying factor for the Flynn effect at younger ages, but even after adjusting for the increase in education between the 1905 and 1915 cohorts, the 1915 cohort still performed better in the cognitive measures, which suggests that changes in other factors such as nutrition, burden of infectious disease, work environment, intellectual stimulation, and general living conditions also play an important part in the improvement of cognitive functioning. The fact that the physical performance tests did not improve could suggest that changes in the intellectual environment rather than in the physical environment are the basis for the improvement. Irrespective of the mechanism, that cognitive functioning is improving as more people live to very old age is encouraging. This improved cognitive functioning might have been expected to be accompanied by a reduction in depression symptomatology, but we recorded no differences between cohorts for this outcome in either men or women. However, contrary to the finding of improved cognitive functioning across successive cohorts of younger (age <75 years) adults (ie, the Flynn effect), such cohorts seem to be at an increased risk of depression.[23] Consequently, that we noted no differences in depression between the 1905 and 1915 cohorts could be a positive finding, although we cannot be certain of the applicability of this cohort effect on depression to very elderly people.

Most of the previous studies into cohort differences focused on people younger than 80 years, and few have focused on very elderly people and included those living in residential care. In a Swedish study,[24] an increase in cognitive impairment was detected between 1992 and 2002 in people older than 77 years. In a study[25,26] of Danish centenarians born in 1895–96 and in 1905, both the proportion of cognitively impaired individuals and the mean score from mini-mental state examination did not differ significantly between the two cohorts, although activities of daily living scores improved for women. However, the sample size in both studies was small.[24–26] A larger Finnish study[18] of nonagenarians in Tampere was based on a questionnaire survey and so did not include cognitive or physical tests, but the investigators reported stable frequencies of disability in 2001–07. In the USA, a series of analyses of data from the Health and Retirement Survey of people aged 70 years and older showed mixed results; Freedman and colleagues[27] reported improvement in cognitive functioning for individuals aged 80 years and older from 1993 to 1998, whereas Rodgers and colleagues[28] noted little improvement from 1993 to 2000 when age distribution and practice effect from previous study participation were taken into account. Langa and colleagues[29] extended the study period to 2002 and noted reduced prevalence of cognitive impairment, in agreement with the findings of Sheffield and Peek,[19] who reported

> ***Panel:* Research in context**
>
> **Systematic review**
>
> We searched PubMed for reports published before Feb 14, 2013, using the search terms "oldest-old", "old age", "nonagenarians", "centenarians", and "cohort differences". We also checked the reference lists of reports identified in the search. To include the most recent demographic data available, we accessed the Human Mortality Database.[3] In line with previous research, recent cohort comparisons[7,9,10,18–20] reached differing conclusions about the health outcomes between cohorts, but the studies that used physical and cognitive testing generally focused on younger elderly people (age <85 years) and excluded those in residential care.
>
> **Interpretation**
>
> Our results show that the Danish cohort born in 1915 had better survival and scored significantly better on both the cognitive tests and the activities of daily living scale than the cohort born in 1905, despite being 2 years older at the time of assessment. This finding suggests that more people are living to older ages with better overall functioning. If this development continues, the future functional problems and care needs of very elderly people might be less than are anticipated on the basis of the present-day burden of disability.

that, based on data up to 2004, improvement in education contributed to reductions in cognitive impairment in elderly people, particularly black and Hispanic people in the USA. However, the mean age of participants in these studies was in the late 70s, and people in residential care were not included except in the study by Langa and colleagues,[29] who included such data for the 2002 study period only. US studies of cohort change in disability among elderly and very elderly people have also had mixed findings. Data from the National Long-Term Care Survey for 1982–2004 suggested that younger cohorts of elderly people are living longer in better health,[30] whereas analyses based on the National Health And Nutrition Examination Surveys for 1988–94 and 1999–2004 showed an increased prevalence of disability in people aged 60–69 years, no change in those aged 70–79 years, and a reduced prevalence of functional limitations in more recent cohorts of people aged 80 years and older[20] (a finding that contrasts with the results for mobility functioning from the US National Health Interview survey[7]).

Our study addresses many of the major challenges in cohort comparisons of very elderly people by having large, national, and well-defined birth cohorts (with a narrow age range within each cohort) born 10 years apart and including people who live in residential care. The same study design and survey instrument were used for both surveys, and both studies had similar response rates. The surveys were each done within a 3-month period and were both intake surveys—ie, the assessment was the first time that any of the participants had taken part in the survey, so no opportunity existed for practice effects on cognitive tests, which is a known cause of bias in comparisons of cognitive test results.

The physical and cognitive functioning outcomes used in our study have previously been shown to be reliable and valid in the 1905 cohort and in other cohorts of elderly Danish people,[12–17] and these outcomes cover the most important domains in very elderly people. However, our analyses do not include diseases. The main reason that diseases were not included is that in nonagenarians diagnostic intensity will be the main determinant of the numbers and types of diseases diagnosed. The attitude towards diagnostic activity and treatment of very elderly people has changed much in the past 15 years, which prevents any valid comparison of disease prevalence between the two cohorts.

A potential limitation of our study was that the 1915 cohort was 2 years older at intake than the 1905 cohort. If we had discovered that the members of the 1905 cohort were better functioning than those of the 1915 cohort, we would not have been able to establish whether this was a cohort effect or an age effect. However, our previous longitudinal analyses of the 1905 cohort showed that, because of selective mortality, functioning was unchanged from age 92 to 100 years for populations, although we did note an individual reduction—ie, the most frail and disabled people tended to die first, leaving the best functioning people in the population.[11] As such, the development over time within the 1905 cohort from age 92 to 100 years was positive and showed that exceptional longevity did not lead to an exceptionally high prevalence of disability.

The present study also shows a positive development between birth cohorts, with no evidence of a net failure-of-success effect. On the contrary, the 1915 cohort performed better on the cognitive tests and the activities of daily living scale than did the 1905 cohort despite being 2 years older, which suggests a net success-of-success effect, with more individuals living to older ages with better overall functioning. However, these findings are limited to one country and two birth cohorts born 10 years apart. The fact that the development within and between these Danish cohorts is positive does not necessarily imply that the same will be true for other countries with different profiles of health and disease and different survival probabilities, or that this trend will continue in later cohorts of nonagenarians. With the rapidly growing populations of very elderly people in high-income countries, surveillance of changes in functioning within and between birth cohorts of people in this age group will be of fundamental importance in the planning of health care, both for individual families and for society.

Contributors

KC, BJ, MM, and JWV designed the study. KC, KA-R, and BJ oversaw the data collection. MT, TS, and AO did the statistical analysis. MT prepared the figure. All authors contributed to data interpretation and the writing of the article

Conflicts of interest
We declare that we have no conflicts of interest.

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References
1 He W, Muenchrath MN. 90+ in the United States: 2006–2008 (American Community Survey Reports, ACS-17). Washington, DC: US Government Printing Office, 2011.
2 Christensen K, Davidsen M, Juel K, Mortensen L, Rau R, Vaupel JW. The divergent life-expectancy trends in Denmark and Sweden—and some potential explanations In: Crimmins EM, Preston SH, Cohen B, eds. International differences in mortality at older ages—dimensions and sources. Washington, DC: The National Academies Press, 2010: 385–407.
3 Human Mortality Database. http://www.mortality.org/ (accessed March 25, 2013).
4 Christensen K, Doblhammer G, Rau R, Vaupel JW. Ageing populations: the challenges ahead. *Lancet* 2009; **374:** 1196–208.
5 Baltes PB, Smith J. New frontiers in the future of aging: from successful aging of the young old to the dilemmas of the fourth age. *Gerontology* 2003; **49:** 123–35.
6 Waidmann T, Bound J, Schoenbaum M. The illusion of failure: trends in the self-reported health of the US elderly. *Milbank Q* 1995; **73:** 253–87.
7 Crimmins EM, Beltrán-Sánchez H. Mortality and morbidity trends: is there compression of morbidity? *J Gerontol B Psychol Sci Soc Sci* 2011; **66:** 75–86.
8 Flynn JR. Searching for justice: the discovery of IQ gains over time. *Am Psychol* 1999; **54:** 5–20.
9 King DE, Matheson E, Chirina S, Shankar A, Broman-Fulks J. The status of baby boomers' health in the United States: the healthiest generation? *JAMA Intern Med* 2013; **173:** 385–86.
10 Gerstorf D, Ram N, Hoppmann C, Willis SL, Schaie KW. Cohort differences in cognitive aging and terminal decline in the Seattle longitudinal study. *Dev Psychol* 2011; **47:** 1026–41.
11 Christensen K, McGue M, Petersen I, Jeune B, Vaupel JW. Exceptional longevity does not result in excessive levels of disability. *Proc Natl Acad Sci USA* 2008; **105:** 13274–79.
12 Nybo H, Gaist D, Jeune B, McGue M, Vaupel JW, Christensen K. Functional status and self-rated health in 2,262 nonagenarians: the Danish 1905 cohort survey. *J Am Geriatr Soc* 2001; **49:** 601–09.
13 Nybo H, Petersen HC, Gaist D, et al. Predictors of mortality in 2,249 nonagenarians—the Danish 1905-cohort survey. *J Am Geriatr Soc* 2003; **51:** 1365–73.
14 Christensen K, Holm NV, McGue M, Corder L, Vaupel JW. A Danish population-based twin study on general health in the elderly. *J Aging Health* 1999; **11:** 49–64.
15 Christensen K, Gaist D, Vaupel JW, McGue M. The genetic contribution to rate-of-change in functional abilities among Danish twins aged 75 years and older. *Am J Epidemiol* 2002; **155:** 132–39.
16 Christensen K, Frederiksen H, Vaupel JW, McGue M. Age trajectories of genetic variance in physical functioning: a longitudinal study of Danish twins aged 70 years and older. *Behav Genet* 2003; **33:** 125–35.
17 Frederiksen H, Hjelmborg J, Mortensen J, McGue M, Vaupel JW, Christensen K. Age trajectories of grip strength: cross-sectional and longitudinal data among 8,342 Danes aged 46 to 102. *Ann Epidemiol* 2006; **16:** 554–62.
18 Sarkeala T, Nummi T, Vuorisalmi M, Hervonen A, Jylha M. Disability trends among nonagenarians in 2001–2007: vitality 90+ study. *Eur J Ageing* 2011; **8:** 87–94.
19 Sheffield KM, Peek MK. Changes in the prevalence of cognitive impairment among older Americans, 1993–2004: overall trends and differences by race/ethnicity. *Am J Epidemiol* 2011; **174:** 274–83.
20 Seeman TE, Merkin SS, Crimmins EM, et al. Disability trends among older Americans: national health and nutrition examination surveys, 1988–1994 and 1999–2004. *Am J Public Health* 2010; **100:** 100–07.
21 Bramell-Risberg E, Jarnlo GB, Elmståhl S. Separate physical tests of lower extremities and postural control are associated with cognitive impairment. Results from the general population study good aging in Skåne (GÅS-SNAC). *Clin Interv Aging* 2012; **7:** 195–205.
22 Schaie KW, Willis S L, Pennak S. An historical framework for cohort differences in intelligence. *Res Hum Dev* 2005; **2:** 43–67.
23 Weissman MM, Wickramaratne P, Greenwald S, et al. The changing rate of major depression: cross national comparisons. *JAMA* 1992; **268**: 3098–105.
24 Parker MG, Ahacic K, Thorslund M. Health changes among Swedish oldest old: prevalence rates from 1992 and 2002 show increasing health problems. *J Gerontol A Biol Sci Med Sci* 2005; **60:** 1351–55.
25 Engberg H, Christensen K, Andersen-Ranberg K, Jeune B. Cohort changes in cognitive function among Danish centenarians: a comparative study of 2 birth cohorts born in 1895 and 1905. *Dement Geriatr Cogn Disord* 2008; **26:** 153–60.
26 Engberg H, Christensen K, Andersen-Ranberg K, Vaupel JW, Jeune B. Improving activities of daily living in Danish centenarians—but only in women: a comparative study of two birth cohorts born in 1895 and 1905. *J Gerontol A Biol Sci Med Sci* 2008; **63:** 1186–92.
27 Freedman VA, Aykan H, Martin LG. Aggregate changes in severe cognitive impairment among older Americans: 1993 and 1998. *J Gerontol B Psychol Sci Soc Sci* 2001; **56:** S100–11.
28 Rodgers WL, Ofstedal MB, Herzog AR. Trends in scores on tests of cognitive ability in the elderly US population, 1993–2000. *J Gerontol B Psychol Sci Soc Sci* 2003; **58:** S338–46.
29 Langa KM, Larson EB, Karlawish JH, et al. Trends in the prevalence and mortality of cognitive impairment in the United States: is there evidence of a compression of cognitive morbidity? *Alzheimer's Dement* 2008; **4:** 134–44.
30 Manton KG, Gu X, Lowrimore GR. Cohort changes in active life expectancy in the US elderly population: experience from the 1982–2004 national long-term care survey. *J Gerontol B Psychol Sci Soc Sci* 2008; **63:** S269–81.